CANADA'S FUTURE IN ASTRONOMY

THE QUESTION OF A LARGE TELESCOPE FOR CANADIAN ASTRONOMERS

Report of the WORKING GROUP ON ASTRONOMY
Submitted to the Science Secretariat, August 12, 1968

ASTRONOMY IN CANADA AND CANADIAN PARTICIPATION IN THE CARSO PROJECT

A Report by the SCIENCE COUNCIL OF CANADA
to the Minister of Energy, Mines and Resources
September 1969

DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA, CANADA

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Queen's Printer for Canada
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FOREWORD

In recent years two studies of astronomy in Canada have been commissioned by the Federal Government.

The first of these studies resulted from a difference of opinion among professional astronomers on the merits of Mount Kobau, B.C., as a site for a large telescope. In June, 1968, the Science Secretariat set up a working group under the chairmanship of Dr. D. C. Rose, to consider the relative merits of completing the Queen Elizabeth Telescope on Mount Kobau or of joining the Carnegie Institution in constructing a telescope in Chile -- the so-called CARSO project. In so far as time permitted, the working group was also to consider the organization and appropriate position of astronomy in relation to the total scientific effort in Canada. The group presented its report in August, 1968.

At approximately the same time, the Federal Government decided for reasons of economy to discontinue construction of the Queen Elizabeth Telescope. It also declined to contribute to the construction of a telescope in Chile.

Interest among Canadian astronomers in a large telescope continued, and a group of western universities set up a consortium, under the name WESTAR, aimed at completing the 157-inch telescope on Mount Kobau with private or provincial funds; Queen's University has since joined the consortium. The Government has undertaken to transfer the assets of the Queen Elizabeth project to WESTAR. Other astronomers urged the Government to reconsider participation in CARSO.

In order to assess the arguments of the astronomers for greater funds within the framework of the government's basic-research budget, the Acting Minister of Energy, Mines and Resources, on May 2, 1969, asked the Science Council to study this question "on the theoretical assumption that the proportion of the budget available for fundamental research in the immediate future would be

the same proportion of the gross national product as it is today". He particularly wanted to know whether "on the basis of this assumption the Science Council would recommend the expenditure of the amount of money required for Canadian participation in CARSO, rather than expenditure of this money on other scientific research or development". The Council was also asked to advise on the best organization of astronomy within the Federal Government.

The Science Council assigned responsibility for the study to its Committee on Physics and Chemistry, under the chairmanship of Professor H. E. Petch. Its report was submitted to the Government on September 23, 1969.

Because of the broad interest which these two studies have engendered among Canadian scientists it has been agreed that they should be published. Through the cooperation of the Science Secretariat and the Science Council the two reports are here published under one cover.

J. J. Greene,
Minister of Energy, Mines and Resources.

Ottawa, Canada.
February 20, 1970.

Report of the

WORKING GROUP ON ASTRONOMY

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Submitted to the Science Secretariat
on August 12, 1968

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INTRODUCTION

The Working Group on Astronomy was asked by the Science Secretariat:

As a first priority

1. To evaluate the merits of the Queen Elizabeth Telescope, the southern hemisphere proposal and other astronomical projects of the Government from the point of view of scientific excellence; this should be considered in the context of the total effort devoted to astronomy by both government agencies and private institutions in Canada.

To the extent and depth that time permits, recognizing the lack of comparative data:

2. To appraise the allocation of resources to astronomy by all agencies in the context of the total scientific effort of Canada, including an assessment of the priority of astronomy in relation to the technical and economic capabilities of the country.

3. To appraise the possible economic benefits to Canada of astronomical research in comparison with other fields of scientific research.

4. To consider the recommendation of the Glassco Commission that all governmental astronomy be combined under one agency.

The Working Group held hearings in Toronto on July 4 and 5, in Vancouver on July 9, in Victoria on July 10 and 11, in Penticton on July 12, in Ottawa on July 16 and in Quebec on July 18. A total of 56 briefs were presented either verbally or written. Professor H.C. van de Hulst, Professor of Astronomy at Leiden, Holland was asked to act as a consultant to the group. He joined the group for the hearings in Vancouver, Victoria and Penticton, and visited Toronto separately. The group, with Professor van de Hulst, visited the Mount Kobau site on July 12. Dr. H.H. Babcock, Director of the Mount Palomar Observatory (the largest telescope in the world) jointly operated by the Carnegie Institution and the California Institute of Technology, visited Ottawa on June 25 and met with the working group.

We wish to thank all those who presented briefs, sometimes coming from some distance to meet with the group at its few hearings. We would particularly like to thank Professor van de Hulst and Dr. Babcock for their assistance and the valuable information given us. We would also like to express our appreciation to the headquarters staff of the Department of Energy, Mines and Resources who placed all desired information at our disposal. Meetings in the various cities mentioned above were held in university conference rooms (in Victoria at the Dominion Astrophysical Observatory). We would like to thank the university authorities for their assistance and the use of their conference facilities.

The members of the working group are:

Dr. D.C. Rose	Formerly Associate Director, Division of Pure Physics, National Research Council, now member of the Department of Physics, Carleton University—Chairman.
Dr. C.S. Beals	Formerly Dominion Astronomer, Department of Energy, Mines and Resources, now a scientific consultant with offices in Manotick, Ontario.
Dr. W.H. Wehlau	Head of the Department of Astronomy, University of Western Ontario.
Dr. D.I.R. Low	Science Secretariat; secretary and organizing officer for the working group.

SUMMARY OF THE WORKING GROUP'S FINDINGS AND RECOMMENDATIONS

The Working Group on Astronomy held hearings in Victoria, Vancouver, Penticton, Toronto, Ottawa and Quebec. Briefs and discussions were held with over 50 of Canada's research astronomers in regard to the objectives outlined in our terms of reference. While the Group considered all phases of research in astronomy including radio, X-ray and optical techniques, its work and recommendations concern mainly immediate problems relating to the need for a large optical telescope.

The proposals for a large optical telescope which were considered by the Group are the following: (1) continuing the Queen Elizabeth telescope project on Mount Kobau in British Columbia; (2) establishing an all Canadian observatory in Chile which would include a 157-inch telescope; (3) joining the Carnegie Institution Southern Observatory (CARSO) project to build a 200-inch telescope in Chile; and (4) doing both projects (1) and (3).

The Working Group was most impressed with the need for Canadian astronomers to have access to a large telescope on a superior observing site. Observatory site investigations by astronomical groups in other countries have shown the north-central region of Chile to have a very high percentage of cloudless nights and to provide outstanding possibilities for large telescopes.

Another consideration was, however, that considerable work has been done on the proposed telescope for Mount Kobau. We have a mirror blank, a grinding machine and a fine team of opticians and telescope designers has been assembled. It is considered that these should be used if possible and our recommendations have taken this into account.

As our first recommendation, it is proposed that a wholly Canadian owned telescope, using the 157-inch mirror blank already made for the Mount Kobau telescope, be built on a suitable site in this region of Chile. We do not, however, think it desirable that Canada develop its own site and have proposed that negotiations start immediately with a United States group, the Associated Universities for Research in Astronomy (AURA) for use of a mountain site owned by them. Present information available to us indicates that the only developed site where space may be available is Cerro Morado. If negotiations for such a site are unproductive, our alternative recommendation would be to join with the Carnegie Institution in their project to build a 200-inch telescope plus two smaller telescopes on Cerro Morado and to complete the construction of the 157-inch telescope on Mount Kobau. The Carnegie Institution has been assured of the lease or purchase of half the mountain top by AURA. The Carnegie Institution would like a decision regarding Canada's interest in their offer by October 1, 1968.

Each alternative solution mentioned above has, of course, its disadvantages as well as advantages and these we have explored in some detail in the report. Although others might weigh differently the various factors involved, we have emphasized in our proposals the value to the future development of astronomy in Canada of an independent effort either in Chile or in Canada. The cost of the first proposal is estimated at between 17 and 20 million dollars. The cost of the second would be about 24 million but its undertaking will likely pose fewer problems for those involved in its construction and operation besides providing more observational equipment.

In addition to the question of a large telescope, the Group also looked at the allocation of resources to astronomy in comparison with other branches of physics. Possible economic benefits of astronomy and the organization of government astronomy were also considered as requested in our terms of reference. Astronomy, we feel, is an important field of study whose discoveries are continuing to have enormous impact on our fundamental knowledge of the behaviour and constitution of matter and in a practical manner on our increasing use of satellites in space. The study of astronomy produces economic benefits mainly of an indirect nature not only in satellite use but also in fields such as nuclear physics and modern technology making use of the laws of

mechanics. Direct benefits may accrue to Canadian industry in the form of telescope orders as a result of the interest which has been aroused among telescope designers in other countries in the Canadian design for a large telescope.

The adoption of either of our recommendations for large telescopes involves expenditures which, when spread over the six to eight years needed for telescope construction, seem to us to be quite reasonable and in line with the planned expenditures in other branches of physics.

Taking into account the present trends in astronomical research, it is our view that the development of astronomy in Canada would be aided if government radio and optical astronomy were combined under the same administrative authority, probably the National Research Council. There is no immediate urgency for this change and it is suggested that for the time being the development of the large optical observatory be left in the hands of those responsible for its present state. It is also suggested that a board be formed consisting of government and university representatives to advise the administrative authority on design, utilization and scientific objectives of the observatory.

THE NATURE OF ASTRONOMY

Astronomy is the study of all extra terrestrial objects and phenomena. To interpret and understand these, studies are carried out in the optical, radio, X-ray and other regions of the spectrum. Optical astronomy provides the means of analyzing the light from the stars, nebulae and other objects yielding information on their chemical composition, temperature and pressure. The positions, motions, light variability and many other properties are determined with optical observations.

The development of radio telescopes in the past two decades has greatly influenced optical astronomy. This development has served to make further observations in optical astronomy even more desirable. For example, the detection of the quasi-stellar objects, which have recently attracted so much attention, comes from radio astronomy. The determination of their velocities of recession and distances is carried out by optical means. Rather than competing, radio and optical telescopes complement each other.

A method of observing that holds great promise for the future of astronomy is that of the satellite-borne telescope. The great advantage of such an instrument is that it does not have to view stellar objects through the earth's atmosphere; the disadvantages are the technical difficulties of getting the telescope into orbit and of making all observations by remote control. Equally important is the great expense to get even a small telescope above the atmosphere. For these reasons, there should be no serious competition between satellite-borne and ground-based telescopes. Observations from above the atmosphere will be concentrated on work not possible from the ground, such as ultra-violet and X-ray studies. Observations at optical and radio wavelengths, which can be made effectively from ground-based telescopes, will continue to be made from the earth's surface.

Astronomy has had a profound influence on the development of earth-based physical science and more specific references are made to this in the body of the report.

THE DEVELOPMENT OF ASTRONOMY IN CANADA

Astronomy in Canada has had a long and distinguished history dating back to the latter part of the 19th century when precise astronomical methods were being applied to the problems of surveying western railway lands and delineating international and provincial boundaries. The era of modern astronomical research was inaugurated in Canada by the eminent astronomer, mathematician and surveyor Dr. W.F. King, who founded the Dominion Observatory in Ottawa in 1905 for the purposes of astronomical and geophysical investigation. This new departure was greatly aided by the fact that a very sound tradition of astronomical teaching had been established by Dr. C.A. Chant at the University of Toronto and most of the staff members of the new Ottawa Observatory were Toronto graduates.

Provision was made at the Dominion Observatory for the fields of positional astronomy (including time service) and solar physics and these studies, through successive stages of modernization, have continued to be active in the Ottawa area till the present date. The study of meteoric astronomy and the investigation of ancient meteorite scars on the earth's surface were later added to the scientific program. The area of astrophysics (mainly astronomical spectroscopy) was taken care of by a modest 12-inch telescope. The limited possibilities of this instrument were exploited to the full by the very gifted scientist J.S. Plaskett who quickly perceived that the future of astrophysics lay with larger and more powerful equipment.

As a consequence of initiative by Plaskett aided by Dr. King, then Chief Astronomer, the Government of Canada in 1918 established the Dominion Astrophysical Observatory in Victoria, B.C. equipped with a reflecting telescope of 72 inches diameter, at that time the largest in

existence. With the aid of a small but devoted staff Plaskett soon turned the Victoria Observatory into a research centre favorably known throughout the scientific world. Plaskett's personal research on the motions and structure of the galaxy brought him world wide fame and many medals and honors while his colleagues and successors were inspired to undertake a variety of different researches resulting in equally solid additions to scientific knowledge.

In 1935, mainly through the efforts of Dr. C.A. Chant, the University of Toronto put into operation a similar but somewhat larger instrument, 74 inches in diameter. Since that time astronomical research in Canada has been dominated by these two institutions and their associated staffs though some excellent work has also been done by other Canadian universities, notably McGill, Queen's and the University of Western Ontario. A significant feature of Canadian astronomy during the past few decades has been the number of university physics department staff members including the very eminent J.S. Foster from McGill who have had recourse to the observing facilities of the large telescopes to help solve the physical problems with which they were confronted.

Following the war, in 1946 the first Canadian observations in radio astronomy were made by Covington at the National Research Council in Ottawa. This beginning was followed by the founding of the Dominion Radio Astrophysical Observatory in Penticton, B.C., the Algonquin Radio Observatory in Algonquin Park, Ontario and by numerous smaller institutions in Canadian universities, notably Queen's and Toronto. In 1967, a group of Canadian university and government radio astronomers teamed up to become the first in history successfully to operate a long base line interferometer (3000 km.) between Penticton and Algonquin Park and to make astronomical measurements of the diameter of radiation sources comparable in accuracy to those done by optical methods. Both optical and radio astronomy, which have to work together to be fully effective, are now combining to study the fundamental problems of the physical universe including the physics of stellar and planetary atmospheres, the nature and distribution of interstellar material and the physical nature of newly discovered objects such as quasars and pulsars.

The evolution of astronomical science during recent years has led to a situation where the problems undertaken at a major observatory have become more like those of a physics laboratory, using as source material not manmade experiments but the observation of matter in quantities and under conditions which cannot be duplicated on earth. Well known examples of this may be found first in the luminous nebulae, thousands of times larger than the solar system with densities lower than the best vacuum on earth but glowing with temperatures of the order of 100,000°; and secondly, the white dwarf stars with densities a thousand times greater than terrestrial rocks but retaining their gaseous nature because of their high temperatures and the fact that they are composed not of atoms but of more fundamental particles which take up much less space than atoms when closely packed together. No longer does astronomy take a back seat to any other branch of science in yielding new physical knowledge. In the words of Professor Oppenheimer, one of the greatest of modern scientists, a 200-inch telescope is worth a major accelerator in adding to our store of knowledge concerning the atoms, molecules and other complex units comprising our physical universe.

Because of the different techniques used, astronomers are frequently classified as radio or optical astronomers. In the government service, these two groups are located in different places and are effectively independent of each other. In the universities, radio and optical astronomy are generally integrated. This report is primarily concerned with the optical astronomers who have a direct interest in a large optical telescope.

Geographically, there are two main groups of astronomers in Canada. The somewhat larger one is in the east, mostly in Ontario; the other group is in British Columbia.

The majority of those in the eastern group are university astronomers. They have substantial research interests in photometry and direct photography as well as spectroscopy. The need for observations for themselves and their graduate students, has led them to urge, essentially unanimously, that Canada establish a major observatory in Chile, jointly with the Carnegie Institution or separately. They feel that this should clearly take precedence over the Mount Kobau Observatory project.

The majority of the astronomers in the west are at the Dominion Astrophysical Observatory, which has the responsibility for the 157-inch telescope,the optical shop, and Mount Kobau. The strong research emphasis there, has been in spectroscopy. An interest in photometry has developed recently, but no one is working in direct photography. They support the proposal for a Canadian observatory in Chile. However, many feel that the Mount Kobau project has a higher priority. They are substantially opposed to joining with the Carnegie Institution, unless the 157-inch telescope is also built on Mount Kobau.

Astronomy in Canada has suffered recently by the untimely loss of Dr. R.M. Petrie who was Director of the Dominion Astrophysical Observatory at the time of his death in 1966. He was an acknowledged leader by virtue of his distinguished research work, senior position and fine personal qualities. Some of the difficulties of the present situation can be traced to the void remaining after Dr. Petrie's death at a critical stage in the planning for a Canadian National Observatory.

PRESENT TRENDS IN ASTRONOMICAL RESEARCH

There are a number of trends in modern astronomy which are so closely interconnected that they cannot easily be separated for discussion. Nevertheless, some of these may be presented as follows.

Signals from astronomical bodies cover all wavelengths from X-rays through the optical spectrum from the far ultraviolet to the deep infra red and on to the radio spectrum from millimeter wavelengths to those of many meters. Very frequently in observing any particular body or phenomenon, it is necessary to use as much of the spectral range as possible and therefore, interaction between radio and optical astronomy is most desirable. Each wavelength interval has its own special problems and advantages. The optical wavelengths are intrinsically capable of carrying more information than any other region of spectrum which can be observed from the surface of the earth. To obtain this information from observations, ever more sophisticated instrumental and theoretical techniques are being developed. Much work remains to be done in order to satisfactorily exploit the information available in optical radiation from astronomical observations.

Similarly, in other regions of the spectrum great gains can be expected. In X-ray and other rocket and satellite astronomy, the directions of development are not yet really discernible, but it appears clear that important results will be obtained by groups who can get new instruments above the earth's atmosphere. In radio astronomy, improvements in engineering and other aspects of observing technique will continue to play a major role. However, increasing emphasis is being given to the analysis and interpretation of the observations, particularly in collaboration with optical observations. This increase in emphasis may be expected to continue as more extensive and detailed observations become available as a result of improved instrumentation.

In the optical field, a large telescope is becoming more and more like an elaborate physical laboratory, with photographic, photometric, photo-conductive and spectrographic techniques employed to receive and analyze the information from celestial sources.

These advances in techniques are accentuating the trend, always present in astronomy, to push observations farther and farther into space, bringing into play larger and larger numbers of physically significant astronomical objects. Recent results of this type of space probing with both optical and radio telescopes have been the discovery of quasars (unexplained bodies of enormous

brightness receding from the solar system at velocities approaching the velocity of light) and pulsars (bodies which give out a pulsating type of radiation covering a wide range of the radio spectrum). These may well be the greatest astronomical discoveries of the 20th century and it is clear that greater telescopic power is needed to make clear their nature. The possibility is being considered that pulsars may be neutron stars with their main masses composed of closely packed neutrons rather than atoms. New observations suggesting as yet unexplained physical processes going on in distant galaxies are also important in both radio and optical astronomy and may well be related to the discovery of quasars and pulsars.

A very major trend in modern astronomy is the study of stellar evolution carried out to a very large extent by photometric measurements of the brightness and colour of large numbers of stars. The formation and evolution of galaxies are related trends, depending to a considerable extent, on the methods of theoretical physics. Theoretical discussions of cosmogony or the origin of the physical universe are also active and depend on all types of astronomical observation for their raw material.

One of the new astronomical developments very much in the public eye is a renewed interest in the physics of the solar system, to some extent associated with the space program. The possibility of manned flights to the moon and Mars has stimulated astronomical observation of these objects by optical and radio methods, while recent measurements of the temperature of Venus have all but disposed of this planet as a landing place for human astronauts. New studies of the sun, in particular of the effects of the solar wind or high speed ejection of atoms from the solar surface, have given us new insights into the character of the earth's upper atmosphere.

A modern astronomical trend of great importance to any group involved in the planning of large telescopes, is the increased participation of non-astronomers such as geologists, geophysicists, radio engineers and nuclear physicists in astronomical observations. This participation is closely related to the tendency already mentioned for a modern large telescope to resemble a physics laboratory with a variety of observational techniques which can be used by a physicist to solve problems which do not yield to his normal laboratory methods. Similarly the geo-scientist may obtain information concerning the interior of the earth by studies of the moon or of meteorites either in orbit, or after forming craters or leaving meteoritic material on the earth's surface. The student of cosmic rays is also becoming deeply interested in astronomical observations especially since it is now known that at least some of these interesting particles emanate from the sun, our nearest star.

The impression we want to leave here is that the continued exploration of more distant and fainter objects in the universe will involve the collaboration of all branches of astronomy and the use of more powerful equipment. It is the need for such equipment that we shall discuss on page 11.

ASTRONOMICAL CONSIDERATIONS RELEVANT TO THE OPERATION OF A LARGE TELESCOPE – PRINCIPAL CRITERIA FOR THE EVALUATION OF AN OBSERVATORY SITE

In assessing any astronomical site zone, there are three principal criteria which are used; all three refer to the atmospheric conditions necessary for good observations. These criteria are as follows:

1. *The number of usable hours per year.* This includes both clear nights and the hours in which observations can be made through light or intermittent clouds.

2. *Atmospheric transparency.* This quality of the atmosphere, is the ability of the atmosphere to transmit starlight. If the transparency of the atmosphere is unsteady and varies from hour to hour, it is impossible to make accurate photometric measurements of the brightness and colours of stars.

3. *The sharpness of stellar images*. (Technically referred to as the "seeing"). The difference between sharp and fuzzy images is illustrated in Fig. 1 where the same stars are photographed under good and bad seeing conditions. Quite frequently the advantage of a sharp image is neutralized by the fact that the image is in a state of irregular motion. The cause of fuzzy images is atmospheric turbulence and the strong temperature gradients within the atmosphere. An increase in image sharpness by a factor two may be as effective, or more so, than a doubling of the telescope aperture.

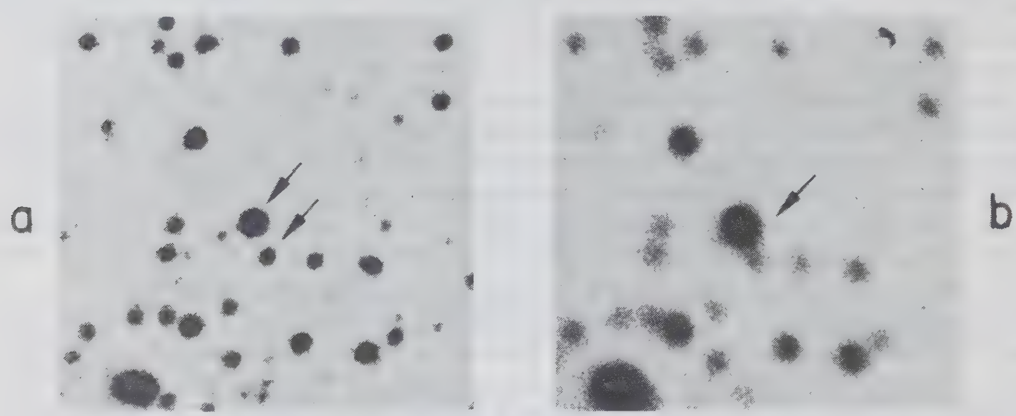

Figure 1.

Other criteria. Darkness of the sky, temperature range, accessibility, snow and ice conditions, water supply, etc. are other criteria that must be considered.

Observations with a Large Optical Telescope

The immediate aims of observations with a large telescope are to determine the brightness and precise colours of astronomical objects, to analyze their light for the determination of chemical composition and a long list of physical properties which are important not only for an understanding of the external universe, but of the earth as well. The three principal techniques used in these observations, which normally required sophisticated ancillary equipment attached to the telescope are:

Spectroscopy

In spectroscopic analysis the light from a star, collected by the telescope, is passed through a spectrograph which disperses the light into its component wavelengths. The resulting spectrogram yields information on chemical composition, pressure, radial velocity and other physical properties.

Sharp images are required because the entrance to the spectrograph, on which the star image is focussed, must be a very narrow slit. Any light not passing through the slit is wasted. (An image

slicer, developed by Dr. H. Richardson of the Dominion Astrophysical Observatory, reduces the light loss at the slit so that sharp images should be less important in the future than now.) Spectroscopy can be carried out with limited atmospheric transparency, but longer exposures are required. The increasing use of precise photoelectric scanning techniques instead of photographic plates to record the spectrum increases the importance of clear skies and constant transparency in spectroscopic observations.

Photometry

This is the measurement of the brightness and precise colours of astronomical objects in order to determine their temperature, distances, etc. In photoelectric photometry, the star image is focussed at the center of a diaphragm which eliminates background sky light and the light from other stars. A system of filters, photomultipliers and electronics measures the intensity of the light passing through the diaphragm.

Clear skies with excellent atmospheric transparency are required for high quality photometry. Sharp images are important so that the smallest possible diaphragm may be used to eliminate background sky light.

Direct Photography

A photograph of a portion of the sky serves for the measurement of positions, the identification of interesting objects such as those found by radio or X-ray astronomers, and the determination of shapes, brightnesses and colours of extended objects such as nebulae and galaxies.

Direct photography requires a clear sky similar to that required for photometry. It is important to have sharp images because they yield more information and can be photographed with shorter exposures, preferably not longer than an hour's duration.

THE NEED FOR MORE POWERFUL EQUIPMENT

In order to continue to contribute effectively to research on the physical nature of the universe and the astronomical objects within it, it has become essential for Canadian astronomers to have a more powerful telescope than the once great Victoria 72-inch telescope and its sister instrument, the 74-inch at Toronto. Investigations of the expansion of the universe, the nature of quasars, stellar and interstellar magnetism, and a host of other problems at the forefront of astronomical research are now closed to Canada. Only a new major instrument at a good site, suitable for a variety of astronomical observations by all Canadian astronomers, will allow a continuation and development of our effective role in astronomical research.

A fundamental difficulty of astronomical observations is the faintness of the objects being observed. Many of the most interesting objects are either intrinsically faint, such as white dwarf stars, or very distant, like the extragalactic nebulae. To obtain sufficient light for analysis, a large telescope is essential. For brighter objects many properties, such as the magnetic fields in stars, can be investigated only with a large telescope with good light gathering power. In addition, some properties of stars change so rapidly that only short exposures can make clear the nature of the changes.

The smaller instruments of past years will continue to make valuable contributions to astronomy. However, observations which can only be made with large telescopes are essential for work on the frontiers of astronomy. Frequently, long series of observations with smaller

instruments must be coupled with comparatively few observations with a large instrument in order to understand certain phenomena.

A telescope of 150 to 200 inches in aperture is required. An instrument of this size is within the present normal engineering capabilities and would be one of the largest in the world. It would enable us to penetrate two to three times as far into space and bring into play from 10 to 20 times the number of celestial objects that we can now observe. With modern design and sophisticated ancillary equipment, such a telescope at a favorable site would be much more effective than is implied solely by the increase in size over our present telescopes.

PROPOSALS DESIGNED TO MEET THE NEEDS OF CANADIAN ASTRONOMY

A. Introductory Remarks

The need for larger telescopes was outlined in the foregoing section. At any observatory site, a large telescope is most efficiently used if there are one or more smaller, less expensive telescopes (of the order of 60 to 80 inches in diameter), closely associated as part of the observatory. All plans for observatory sites include such equipment, but our immediate concern is with making recommendations about the minimal basic equipment to get Canadian requirements established.

The principal criteria for the evaluation of an observatory site include:

1. A maximum number of usable hours — this includes hours of darkness during which observations can be made without haze or clouds, or with only light or intermittent clouds and haze.

2. Number of nights suitable for photometry — these are nights which are free from haze or clouds for at least six consecutive hours.

3. Image sharpness as discussed in the paragraph on "seeing", page 10.

4. Other criteria are darkness of the sky (interference from city lights), temperature range, accessibility, etc.

5. The accessibility of interesting objects in the sky — a telescope in the far north could only see half the sky. Objects in the most interesting parts of the southern sky are never visible in Canada.

In actual practice, a compromise is always necessary. A very high mountain (above the clouds) would mean temperature and climatic conditions that would make the actual operation of a large telescope too difficult. Completely cloud free areas are practically non-existent. Haze is often difficult to detect unless photometric measurements are actually made. The pros and cons of the actual proposals before us are discussed in the following paragraphs.

B. The Mount Kobau Project

The first move toward meeting Canadian requirements was a proposal for a British Commonwealth telescope of 150-inch aperture, located in Australia. Canadian astronomers voted to accept this proposal and a submission from the British Astronomer Royal went to our Treasury Board. The Government at the time, was reluctant to spend the necessary funds (of the order of several million dollars) outside Canada and the proposal was turned down. This sequence of events led Canadian astronomers, particularly those in western Canada, to consider very carefully the possibility of locating a Canadian site for a new large telescope of the order of 150-inch to serve the needs of astronomers throughout the country.

At first, the late Dr. R.M. Petrie, then Director of the Dominion Astrophysical Observatory, was inclined to urge a Victoria location. Before making a decision, however, he instituted a site search in other areas of British Columbia. The site search was carried out by Dr. G.J. Odgers, also of Victoria, and this search soon showed that there were areas in B.C. which offered advantages over Victoria in the matter of astronomical observation.

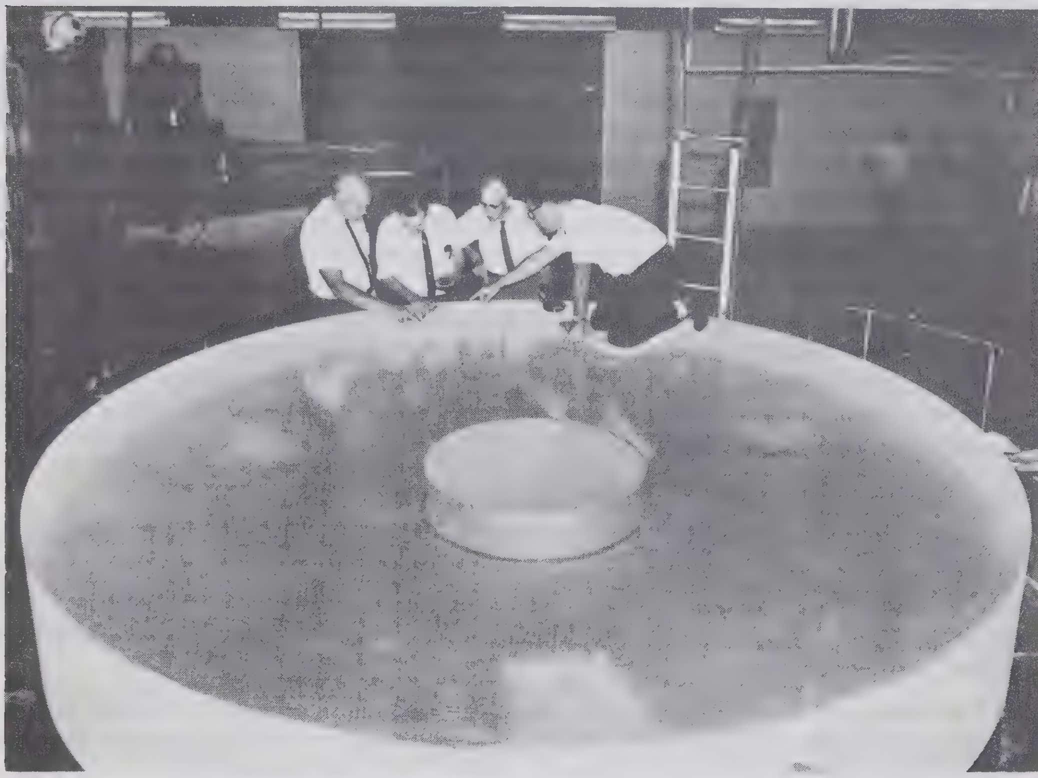

Figure 2. The 156-inch Primary Mirror Blank. Making polarimeter stress tests at the Corning Bradford plant are (L. to R.) N. Van Dyke, R. Dancey, H. Effner and W. Barker. Mr. Dancey is Chief Optician for the project.

The search for an alternative site was mainly confined to the mountainous dry belt of British Columbia and a number of sites from Kamloops to the Canada-U.S. border were carefully examined. Particular attention was paid to the image sharpness since it was this criterion which was most important for the spectrographic observations that made up the bulk of the Victoria observational program. The most favorable location was considered to be Mount Kobau just to the west of the southern end of the Okanagan Valley at a height of 6200 feet. Here the image sharpness was much better than Victoria, while the number of cloud-free hours and the atmospheric transparency were about the same.

While these characteristics were less favorable than the best sites in southwestern United States and South America they were believed to be the best in Canada and it was accordingly decided to make Kobau the site of a national observatory and to equip it with a 150-inch reflecting telescope

and, eventually, other auxiliary astronomical instruments. Government approval was given for the purchase of a quartz mirror blank, 150 inches in diameter (in fact the actual mirror blank turned out to be 157 inches in diameter)* with the necessary grinding equipment, while a road was built to the summit. Plans were also made for the construction of an optical shop on the campus of the University of British Columbia in Vancouver where the grinding and figuring of the telescope mirrors were to be carried out. A team of optical designers and technicians was built up and they are now engaged in preparations for the mirror grinding process and the construction of auxiliary equipment for the 157-inch telescope.

At the time that Mount Kobau was chosen as the observatory site, the director of the project, Dr. R.M. Petrie, was working under what he believed to be a firm directive that any new large addition to Canadian astronomical equipment must be built in Canada. Since Dr. Petrie's untimely death in 1966, the situation has undergone a change. A number of astronomers, particularly in eastern Canada, have become concerned about the question of atmospheric transparency and cloud cover at the Kobau site. Since much of their work is concerned with photometry and direct photography, they have expressed the opinion that a telescope on Mount Kobau would not be adequate for the needs of Canadian astronomy and that the whole question of the site should be reconsidered. They urged that the telescope be relocated in a favorable location in Chile, South America, where conditions of cloud-free sky, image sharpness and atmospheric transparency are superior to those in any other known location. This turn of events has brought the project to a standstill and the present Working Group has been asked to examine the matter and make recommendations for future action.

Advantages of continuing with the 157-inch telescope on Mount Kobau

1. An optical and engineering design of the 157-inch telescope has been prepared indicating that an instrument of high quality with a large Canadian content can be produced. Two original developments in the mechanical design, the mirror support system and the secondary mirror interchange system, appear to have considerable merit and have attracted the interest of telescope designers in other countries.

2. The skilled groups working in optics, telescope design and instrumental development, both within the government service and in private industry, would be continued without interruption. The assembly and training of such groups is difficult and time consuming. The continuance of these groups has scientific and possible commercial advantages. Several Canadian firms are attempting to obtain contracts for the design and manufacture of large telescopes planned by other countries. The continuance of the 157-inch telescope project would enhance these possibilities.

3. Spectroscopic observations of high quality could be obtained at Mount Kobau.

4. Canadian astronomers in the west, particularly the resident staff, would gain experience in the operation, instrumentation and use of a large, modern telescope.

5. This observatory would be completely under Canadian control and on Canadian soil.

Disadvantages

1. The site, although very useful for spectroscopy, is generally unsatisfactory for precise photometry and direct photography. The disadvantages of this site appear most clearly when it is compared with known sites in favorable locations in South America. Here there appears to be no

*See figure 2.

doubt in the fields of photoelectric photometry, direct astronomical photography and spectroscopy, the Chilean sites are superior by a factor of the order of ten.

2. Astronomers located at some distance, particularly in eastern Canada, would not be able to use the observatory effectively because the probability of an individual successful observing run is not sufficiently high, particularly in the winter months. Hence, it would be difficult for the observatory to function as a national observatory.

3. The cost per observation would be much higher than at most other observatories with large telescopes.

C. Proposal to Establish a Canadian Observatory in Chile

In order to make clear the rationale of the proposal that the major Canadian telescope be in Chile rather than in Canada, it is desirable to give some quantitative data. Values associated with the principal criteria for assessing a site are:

	Mount Kobau, B.C.	*Chile*	*Factor of advantage Chile over Mt. Kobau*
Number of usable hours per year . . .	1300	2600	2X
Photometric hours per year	300	2175	7X
Image sharpness*	1.5″	0.7″	4X

The effectiveness of the observatory is proportional to the product of the third factor with either the first or second, depending on the specific use of the telescope. Consequently, the sites in Chile are at least a factor of the order of ten times more effective than Mount Kobau. The specific sites referred to in Chile are Cerro Tololo and Cerro Morado.

AN OBSERVATORY IN CHILE COMPARED WITH MOUNT KOBAU

Advantages

1. Photometry and direct photography, in addition to spectroscopy, would be carried out very successfully.

2. Observing efficiency would be about ten times greater than at any known Canadian site. This represents a considerable decrease in cost per observation.

3. The telescopes would serve the observational needs of *all* Canadian astronomers.

4. Smaller telescopes could be put into effective operation, relatively quickly.

Disadvantages

1. The remote location will make installation and maintenance of the telescopes and other equipment somewhat more difficult. (These difficulties can however be overcome as has been shown by the Associated Universities for Research in Astronomy (a United States group) at Cerro Tololo and by the European Southern Observatory at La Silla.)

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*As defined in the paragraph under "seeing", page 10. These figures represent image diameter in seconds of arc. The advantage is inversely proportional to the square of the image diameter.

2. The location in a foreign country will leave the observatory subject to legal and political conditions not in our control. (Fortunately, astronomical observatories operated by other countries are regarded as beneficial institutions. It would be desirable scientifically and politically to encourage the active interest of Chilean scientists in our observatory.)

3. There would be some increase in travel expenses. (This is not a large item in comparison with other expenses of installing and operating an observatory — probably less that 10 per cent of the operating expenses. Nonetheless, it would be essential that observers who are granted observing time also be granted travel expenses. Airplane transportation to Chile is relatively convenient.)

A WHOLLY CANADIAN 157-INCH TELESCOPE IN CHILE

This proposal is that Canada locate its major observatory in Chile.

The Telescope

The major instrument would be a 157-inch telescope. The difference in latitudes at Mount Kobau (49°) and for the sites in Chile (30°) would require changes in the design of the 157-inch telescope planned for Mount Kobau. One solution could be to use the design of the Associated Universities for Research in Astronomy (AURA) for telescopes of similar size under construction for Cerro Tololo and Kitt Peak. The design team for the Mount Kobau telescope cooperated extensively with the AURA group and their designs have a number of common features. The existence of this design may prove useful in consideration of the design for the proposed Canadian 157-inch.

Telescopes of smaller aperture (60 to 80 inches) would be required. Most astronomical programs involving a large telescope require observations of brighter objects which can be made most efficiently with a smaller instrument at the same site.

The Site

Three mountain sites have been investigated by various American teams, and the European Southern Observatory group is using a fourth. The three sites investigated by the American group are Cerro Morado, Cerro Tololo and Cerro Pachon. Of these, Cerro Morado, and Cerro Tololo are the more accessible; Cerro Pachon is possible but its higher altitude means it has a more severe climate and site development would be more expensive. The European group's site at La Silla is considerably farther north. It is understood that the climatic and "seeing" conditions are about equal at all four sites.

What appears now to be the most desirable and practical site would be on Cerro Morado next to the Carnegie Institution Observatory which will have half of the mountain top. The mountain belongs to the Associated Universities for Research in Astronomy. There is a possibility that they would be unwilling to give up the remaining half of Cerro Morado since this is a very desirable site and their site on Cerro Tololo is now completely filled. The site at La Silla is also filled up.

Development of a different mountain top such as Cerro Pachon, would require a site survey, investigation and development of the water supply (a significant problem in such an arid region), extensive road building, electrical supply, negotiations for the site, etc. These problems can be solved, but the costs would be wholly borne by Canada and some delay in initiating use of the site for astronomical observations would probably result.

Advantages of an All-Canadian Telescope in Chile

1. The astronomical instruments of the observatory would be wholly owned and controlled by Canada. Sharing of the top of Cerro Morado with the Carnegie Institution would still give Canada an observatory more truly its own. An all Canadian telescope would make much easier the

programming of observations by Canadian astronomers and the foreign guests of the Canadian Observatory that such a telescope would undoubtedly attract. There are, of course important aspects of astronomy where a 200-inch telescope would have substantial advantages but this must be weighed against the advantage of having full time on a 157-inch telescope.

2. A wholly owned Canadian telescope would give Canada the responsibility of determining where and how the telescope would be built and the corresponding opportunity to encourage Canadian industry in telescope construction.

3. The fine team of optical designers and technicians which has been assembled to grind and polish the 157-inch mirror blank for Mount Kobau could be retained and strengthened. It would serve not only to finish the optical parts of the 157-inch telescope but could form the nucleus of a permanent research group to design ancillary equipment for this and other telescopes.

4. Since the mirror blank and the grinding and polishing equipment are now ready for the 157-inch telescope it should be possible to complete and operate the instrument in a considerably shorter time than for any alternative proposal.

Disadvantages

1. The 157-inch telescope will be considerably less powerful than a 200-inch. This is partially, but not fully, offset by having twice as much time available to us on the 157-inch telescope. When the 157-inch telescope is completed it will be one of several such instruments, while the 200-inch will be the largest and most effective one.

2. If it is necessary for us to develop our own mountain top, costs will rise substantially.

D. The Joint Project in Chile with the Carnegie Institution of Washington

The Carnegie Institution of Washington are planning to build a new observatory on Cerro Morado in north-central Chile and have invited Canada to participate in joint sponsorship of the project. This would mean an equal sharing of responsibility between the Carnegie Institution and the Canadian astronomers in the planning, financing, construction and operation of the observatory. On the basis of the experience of Carnegie Institution with the 200-inch telescope and their knowledge of the Cerro Morado site, they have estimated the total cost to be $21 million Canadian, half of which would be Canada's share. A decision on this offer has been requested by October 1, 1968.

The observatory to be shared jointly would consist of three telescopes: (a) a 200-inch telescope of similar design to the very successful 200-inch Hale reflector at Mount Palomar in California (Palomar is operated by the Carnegie Institution); (b) a 60-inch general purpose telescope; and (c) a 48-inch Schmidt wide-angle photographic telescope.

The site is on land owned by AURA and the Carnegie Institution plans to purchase or lease the site from them. Cerro Morado is at an altitude of 7000 feet and its nearly flat summit area can accommodate a number of telescopes without any major earth moving or blasting. The region is arid and annual rainfall averages about four inches. Occasional winter storms may bring a foot or two of snow to the summit. Water is therefore a problem in the region but springs about two kilometres from the summit have never been known to go dry and would be the source of water for the observatory. The Carnegie Institution is now starting the installation of a water system, road improvements and other required services on the site.

Advantages

1. These telescopes will be the most effective in the world. The 200-inch telescope will be twice as powerful an instrument as a 150-inch telescope on the same site. The larger telescope will be able

to make observations not possible with any other telescope in existence. The 60-inch and 48-inch Schmidt will be very effective telescopes. The 60-inch should be completed on the site some years before any large Canadian telescope could be completed.

2. The telescopes and the domes to house them will use proven designs which will reduce costs and technical difficulties.

3. The site has been thoroughly investigated and is known to be entirely suitable for the observatory. Much of the essential but laborious preparatory work has been done — road construction, investigation of water supply, etc.

4. The cost will be very low for the instruments provided. This is primarily a consequence of 2 and 3. Negotiations with the Carnegie Institution should allow a large fraction of the fabrication to be done in Canada.

5. Association with the outstanding group of astronomers and technical staff at Mount Wilson and Palomar Observatories would be stimulating. Joint operation will give the best ancillary apparatus.

6. Smaller telescopes owned wholly by Canada could be installed on the site.

7. If the 200-inch mirror was figured in Canada it would bring our optical team considerable prestige.

Disadvantages

1. Joint ownership and operation might be more difficult than for a wholly Canadian observatory. Development of ancillary equipment might be dominated by the Carnegie Institution astronomers unless Canadian astronomers are quite active.

2. The observatory might be regarded by others as a U.S. establishment with Canada as a "junior partner".

RECOMMENDATIONS

The Working Group has tried very hard to look at all aspects of the large telescope question referred to in its first term of reference. Two factors appear to rise above all others. In the first place, there is a strong feeling shared by many Canadian astronomers that Canada must have a telescope or have access to a telescope in the southern hemisphere. Secondly, there is considerable doubt that a 157-inch telescope on Mount Kobau would be a national observatory; for photoelectric photometry, the uniformity of the atmospheric transparency at the site is not adequate for work of high precision and in fact, many eastern astronomers whose principal interest is photometry, would probably not use the 157-inch on Kobau at all.

It is therefore recommended that out first objective should be to build a Canadian observatory on a mountain site in Chile which, besides the 157-inch telescope, would include a telescope 60 to 80 inches in diameter as auxiliary equipment.

We feel that the Canadian astronomical community is large enough to be able to operate independently of any United States group, and that Canadian astronomy in the long term, would be strengthened by such an undertaking. The most important advantage of an all Canadian observatory would undoubtedly be the challenge to originality and the incentive to leadership that the possession by Canada of such an institution would provide. The explosive possibilities of such a situation were well illustrated by the outburst of activity which followed the completion of the

72-inch Canadian telescope in 1918. There is very good reason to expect that history would repeat itself with a much larger instrument on a suitable site in the exceptionally favorable atmospheric conditions of northern Chile. However, before the decision can be taken on this proposal, the crucial question of a suitable site in Chile, which the Working Group was not in a position to investigate, must be answered. The outstanding present possibility is a position on the plateau of Cerro Morado which is owned by the Associated Universities for Research in Astronomy (AURA), whose present plans for the site indicate that space may be available. Other known astronomical sites in Chile would require lengthy evaluation, from the point of view of access, water, communications, site foundation, etc. We would strongly recommend that the Board of AURA be approached in this regard as soon as possible.

The urgency of making this enquiry is dictated by the terms of our alternative proposal which we would recommend be followed if no suitable site is available to us. The Carnegie Institution would like confirmation of Canada's interest in their offer by October 1, 1968.

As an alternative, it is recommended that the 157-inch telescope on Mount Kobau be completed and established at that site according to the plans already approved and at the same time, Canada should accept the CARSO offer for joint construction and ownership of a 200-inch telescope on Cerro Morado in Chile.

This proposal would lack the unifying effect on Canadian astronomy that the all-Canadian 157-inch in Chile would have but it would satisfy the demand for observing time in the southern hemisphere and meet the original requirements, at least of government astronomers, for a large telescope in Canada. The second proposal would be more costly than the first; the costs are approximately $15 million for a 157-inch on Mount Kobau and an optical shop plus $10 million for the Canadian share of the CARSO project compared to perhaps $17-20 million for a 157-inch in Chile, depending on the extent of site development undertaken for the Canadian telescope. Rough estimates of the cost per year of Kobau and CARSO indicate that an annual maximum of $5 million would be reached about four years from the start of construction with an average annual expenditure over ten years of $2.5 million.

We regret that as long as a substantially superior site such as that in Chile remains a possibility, we are unable to recommend that the Mount Kobau proposal alone, be implemented. As stated earlier, we feel that the site is inadequate to serve the needs of many of the Canadian astronomers and cannot be considered the location of a truly national observatory.

The Group also regrets that it cannot recommend that the CARSO offer, alone, be accepted because in the long term the association of the major Canadian observatory with a group of such strength and eminence is unlikely to produce the desired degree of independence in Canadian astronomy, particularly in optics and instrumentation, that we feel is necessary to its future growth and success.

FINANCIAL CONSIDERATION AND ALLOCATION OF RESOURCES

The following paragraphs will outline briefly the overall costs of proceeding with our primary recommendation, our alternative recommendation and compare these with costs in other branches of physics. The second item in the terms of reference of this study group asked the group "to appraise the allocation of resources by all agencies in the context of the total scientific effort of Canada including an assessment of the priorities of astronomy in relation to the technical and economic capabilities of the country". To do this in detail would be too tall an order with the time and resources at our disposal. However, using existing data and estimates, we can fit the

proposal into the context of physical research and this report should present some picture of its importance.

First, consider the cost of the proposals we recommend. The cost of our first recommendation is difficult to assess. The estimates for the construction of the QE II telescope are given in a preliminary report by the consulting engineers, "Dilworth, Secord, Meagher and Associates", Volume 2, Part B, Section G, as a total of $12,558,000 spread over eight years. This amount is only for the telescope and its housing, dome, etc. Some of this has already been spent namely, the purchase of the mirror blank which cost $1,038,000. This blank would be used. This fixes the remaining cost at $11,520,000. According to information presented by Dr. J.H. Hodgson, some savings might reduce this slightly, but there would be increased cost to Chile.

This figure does not include the optical shop nor site development. The optical shop is estimated at $1,100,000 as a minimum. A residence for staff (permanent and transient) would have to be built at the site. If we were accepted on one of the American sites on Cerro Morado, there would be an appreciable contribution for site development. These might be estimated as follows:

Optical shop	$1,100,000
Auxiliary 60 to 80 inches diameter telescope	2,000,000
Contribution to site development	1,500,000*
Residences, etc.	500.000*
	$5,100,000

Transport of observatory equipment to Cerro Morado would involve another figure which we are not capable of estimating but propose to fix at about $100,000.

The cost of the minimal plan at an American site in Chile would therefore be $16,700,000. If the American site was not used or negotiations with the Chilean Government were prolonged or difficult, this cost might be very much higher. The only safe comment to make, is that the cost would be between *17 and 20 million dollars.*

The costs of our *alternative proposal,* namely to build the proposed telescope on Mount Kobau, and at the same time join the CARSO project with equal shares in the 200-inch telescope, are as follows:

It is estimated that in consideration of money already spent, the minimal Mount Kobau project** could be completed for *$14,300,000*.

The CARSO group has made a detailed estimate of costs for the 200-inch telescope and site development on Cerro Morado in Chile. An updated estimate of this is $21,000,000 Canadian, of which it is proposed we pay half. The overall cost of our alternative recommendation is therefore

Mount Kobau	$14,300,000
Half share in the CARSO plan	10,500,000
Total	$24,800,000

*These figures are rough estimates.

**A complete observatory on Mount Kobau would require at least one smaller telescope (of the order of 60 inches). In recommending the combined proposal, the proximity of smaller telescopes in Victoria and in view of the nature of the work to be done, the smaller telescope does not have as high a priority as it would at an observatory in Chile. It is therefore omitted from this estimate.

In the report *Physics in Canada*, there is an analysis of the number of research scientists in various branches of physics and the overall expenditure in each. Taking figures from that report and quoting the numbers in terms of "Full Time Equivalent (FTE)" scientists, that is correcting for the estimated fraction of time a university professor gives to research, the following data can be shown. (These figures do not include graduate students who are very important in the research output of a normal university department.)

TABLE I

TOTAL OF PHYSICISTS IN CANADA

Numbers of Physicists in terms of Full-Time Equivalent Research Workers.

	1966	1971
Universities	425	967
Government	629	1016
Industry	166	511
Total	1220	2494

Overall Expenditure per year

(Total support in Millions of dollars)

	1966	1971
Universities	28.3	73.0
Government	36.9	62.3
Industry	5.0	26.0
Total	70.2	161.3

TOTAL FOR ASTRONOMY ONLY

Staff in terms of Full-Time Equivalent Research Workers.

	1966	1971
Universities	11	23
Government	56	100
Industry	nil	nil
Total	67	123

Cost per year for Astronomy in Millions of dollars.

	1966	1971
Universities	0.6	1.9
Government	4.6	8.3
Total	5.2	10.2

Astronomy represents

	1966	1971
Percentage of physics research workers	5.5%	5.0%
Percentage of overall research budget for physics	7.4%	6.3%

These figures include the construction of the Queen Elizabeth telescope on Mount Kobau as it was planned late in 1966 when the Report on Physics was drafted. The overall amounts included then represent about the current estimated cost. They include both capital and operational expenditure and 1971-72 represents about the year that capital expenditure might be expected to be a maximum. The fraction of the expenditure on astronomy seems reasonable in relation to the number of scientists concerned. The carrying out of our primary recommendation might increase the overall cost by a maximum of about 6 million dollars spread over several years. Assume it is 1 million per year, then the percentage of cost of physics research, which in 1971 might be allotted to astronomy, would be 6.9 per cent instead of 6.3 per cent. If our alternative recommendation were adopted, that is that we should proceed with both the Mount Kobau project and the CARSO proposal, the increased cost over the older plan would be about $10 million. Spreading this over 5 years, would increase the percentage of physics research proposed for astronomy in 1971 to 7.6 per cent. Even this figure does not appear to us to be unreasonably high.

Another way of examining costs to make comparisons with other branches of physics easier, is to estimate the cost per research astronomer per year. The unit is again the full time equivalent FTE research scientist. In the case of university astronomers who have average teaching loads one half of their time is considered to be available for research.

The cost per full-time equivalent astronomer may also be divided between operating expenses and capital costs of new equipment. The operating costs in 1966 were estimated at $42,500 per research astronomer per year with the expectation that this would rise to $48,000 by 1971. The overall cost from Table I is estimated at $83,000 per astronomer in 1971. The difference represents the estimated capital investment including not only the Mount Kobau project as previously planned but other improved facilities for instance in radio astronomy. The increased costs of following our primary recommendation and our alternative recommendation are shown in the following table.

TABLE II

Estimated cost per full-time Equivalent Research Astronomer for the year 1971. (This year was chosen as it might represent the year of maximum expenditure in the large telescope programme).

Cost per astronomer in 1971 as estimated from the plans available in 1966 (This includes the Mount Kobau project as originally planned)	$83,000
Cost including the plan recommended in our primary recommendation, that is a Canadian observatory in Chile instead of on Mount Kobau	$91,000
Cost including the plan outlined in our alternative proposal, that is both a large telescope on Mount Kobau and joining the Carnegie Institution project	$99,000

The life of these large telescopes is very long and the operating cost for the maintenance and use is smaller than in the case of some other branches of physics. In round figures, the basic operating costs per full-time equivalent research astronomer should level off at about $50,000 per year. However, development of new equipment for telescopes in the case of optical astronomy and for radio astronomy and other applications will be necessary. The annual cost therefore can never be reduced to the basic operating cost. It is estimated that when the recommended observatory plans are completed, the cost per full-time equivalent research astronomer could be levelled off at $85,000 per year leaving reasonable leeway for future development of capital equipment.

In Table III, the above costs are compared with other branches of physics. These figures were copied from the report *Physics in Canada* for the year 1971 as estimated when that report was prepared.

TABLE III

Cost per full-time equivalent research scientist for the year 1971 as estimated in 1966, when the report "Physics in Canada" was prepared. The figures are for subdivisions of physics research in government laboratories only but are representative of University costs as well.

Astronomy	$83,000	Elementary particle	100,000
Upper atmosphere	59,000	Solid state	95,000
Classical	44,000	Plasma	43,000
Earth	66,000	Theoretical	20,000
Meteorology	73,000	Biophysics	26,000
Atomic and molecular	34,000		
Nuclear	230,000	Average	$60,000

Astronomy, if fixed temporarily at a maximum of $99,000 (corresponding to our alternative proposal) then falling to about $85,000 in a few years, is high but not outstandingly high. In view of the importance of astronomy in relation to other branches of physics which are more closely associated with industry (i.e. nuclear physics, space physics and plasma physics), we do not feel that approval of either our primary or our alternative recommendation would represent an undue strain on Canada's allotment of finances for scientific research.

THE ECONOMIC BENEFITS OF ASTRONOMY

Item 3 in the terms of reference of the Working Group asks for an appraisal of the economic benefits to Canada of astronomical research in comparison with other fields of scientific research. In the opening paragraphs of this report, the position of astronomical studies in the historical development of the physical sciences was mentioned. Training in astronomy covers training in the most exact physical measurements, the basic laws of mechanics, the atomic and nuclear structure of matter and the behaviour of large masses of matter both in its solid, liquid and gaseous state.

The nature of gravitational forces and nuclear binding forces are still unknown to man though years of study and measurement have produced an appreciable knowledge of the physical laws resulting from such forces. Astronomical observations and philosophies of religion were closely interwoven in the minds of ancient philosophers and only became separated with the separation of exact measurement in the physical world from the emotional feelings of man. The world of space including much of astronomy and the world of high energy nuclear physics represent the boundary areas of human knowledge. Combine these with man's everlasting curiosity with the visible sky and it is evident that research in astronomy cannot be neglected in any country which considers itself to be achieving an advanced stage in technology.

On the purely practical side astronomy, apart from satisfying man's curiosity about the visible heavens, has to its credit important achievements. Some important advances, being part of everyone's life, are probably least obvious. The maintenance of standard time evolved from astronomical studies requires continued observation. Ability to navigate is a direct result of astronomical knowledge. It was mentioned before that the laws of mechanics on which our mechanical engineering is based came from astronomical studies. The highest energies found in elementary particle physics still come from sources in the sky and this will be so for some time in spite of the large nuclear accelerators that are now being built. Geodetic surveys, or a knowledge of the extent and area of the lands under Canadian sovereignty, would not be possible without astronomical measurements. It is only during the last few years by the use of artificial satellites that we are acquiring some knowledge of the exact shape of the earth. This could not be done without the massive background of astronomical knowledge and training that exists throughout the world today.

The accumulated economic benefits of astronomy in the fields of navigation and engineering as well as of atomic and nuclear physics have far surpassed all the funds that have been devoted to astronomical research during the past two centuries. Although we cannot predict which of the present and future developments in astronomy, such as quasars, neutron stars, gravitational lenses, etc., will produce results of practical value, past experience indicates that contributions in the future will be even greater than those in the past.

A practical item in the Canadian economy, though small in the overall effect, lies in the capability of the group of opticians and designers within the government service and private industry that have been assembled to complete the 157-inch telescope. The telescope design and the large mirror polishing machine have received very favourable comment by those competent in

this highly specialized field in other countries. Foreign business in sight for which they could compete might represent $30 million during the next few years. Of course, the completion of the 157-inch telescope would put them in a much stronger position to get this business.

The great public interest in astronomy is exemplified by the membership of the Royal Astronomical Society of Canada (RASC) (2500) and the number of Planetaria that are being established in several Canadian cities. The RASC has both amateur and professional membership and has branches in most of the large centres in Canada. The number of members of the public who visit existing observatories each year is counted in the tens of thousands. The benefits of wide public interest in astronomy are impossible to estimate but are very real in terms of the educational value to the public particularly in encouraging an interest in science generally among young people.

ORGANIZATION OF ASTRONOMY IN CANADA

The recommendation of the Glassco Commission to consolidate all federal astronomical research within the National Research Council was discussed in a number of briefs submitted to the Working Group. The interest in this question was, generally speaking, secondary to the main interest of a solution to the large telescope problem. However, although few strong feelings were expressed on the subject, the Group formed the impression that the changes recommended by the Glassco Commission would be welcome in the long term. There seems to be little pressure for immediate organizational changes.

At present, optical astronomy in government is all conducted within the Department of Energy, Mines and Resources. Work in radio astronomy goes on in both the Department of Energy, Mines and Resources and the National Research Council. The Energy, Mines and Resources' effort is located at the Dominion Radio Astrophysical Observatory (DRAO) in Penticton and the National Research Council operates the Radio Observatory in Algonquin Park. The group at DRAO although very active, is small and suffers from a lack of technical assistance and engineering back up. DRAO cooperates closely with ARO but it seems that putting DRAO and ARO in the same administrative body within the National Research Council would further enhance this cooperation and give the DRAO better access to the engineering support of the Council. Whether or not radio and optical astronomy should be merged administratively is a more difficult question.

Discussion of the organization of governmental astronomy would be incomplete without some mention of the rapid development of astronomical research and teaching in the universities. Fifteen years ago there was only one university, the University of Toronto, actively engaged in research in astronomy. Now there are nine, with at least six others planning or considering work in astronomy.

The majority of these universities are without their own observational equipment suitable for research. It is important that telescopes and ancillary apparatus adequate to do really effective research be provided. At the same time, care must be taken to avoid a proliferation of astronomical centres which would undoubtedly be at the expense of excellence at any of them.

Some of the needs of the astronomical research are best met by the provision of national facilities available to all universities. These facilities will be of considerable importance in the development and organization of governmental astronomy.

The closer interaction of radio and optical astronomy is undoubtedly desirable but the question of the large optical telescope must take precedence over a merger of the two fields. It is

our feeling that until the large telescope project is further advanced, it should remain in the Department of Energy, Mines and Resources, where a certain amount of momentum has already been built up. We do want to emphasize that in whatever department or agency the observatory project rests, a board or boards should be formed consisting of government and university representatives to advise the administrative authority on questions of design, utilization and scientific objectives.

In the long run, there would seem to be strong reasons for radio and optical astronomy to be together preferably under the National Research Council. It is our opinion that it is the capabilities of the individuals that count more than the nature of the organization and that the scientific objective must take precedence over administrative convenience.

A Report by the

SCIENCE COUNCIL OF CANADA

ASTRONOMY IN CANADA AND CANADIAN PARTICIPATION IN THE CARSO* PROJECT

Submitted to the Minister of Energy, Mines and Resources
September 1969

*The CARSO Project (the Carnegie Southern Observatory) is a proposal by the Carnegie Institution for the construction of a major astronomical observatory in the southern hemisphere, on a mountain top in Chile. If it becomes a joint project, it would be renamed.

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RECOMMENDATION

The Science Council, having studied all aspects of astronomy in Canada and the CARSO Project in particular recommends that an agreement be concluded with the Carnegie Institution for the cooperative development on a 50-50 cost-sharing basis of a 200-inch optical telescope and related facilities, provided that the following conditions are met:

1. That Canada's contribution be scheduled as ten equal payments of $1,200,000 (in 1969 Canadian dollars) per year, beginning in 1971, i.e. 50 per cent of the currently estimated total cost of $24,000,000.

2. That, as a consequence of these contributions, Canada should have exclusive right to 50 per cent of the usable viewing time of the telescope and its related facilities, the Carnegie Institution having the right to the remaining 50 per cent.

3. That Canada and the Carnegie Institution jointly should be prepared to offer up to 10 per cent of the total usable viewing time for use by Chilean astronomers.

4. That the total amount of money contributed by Canada be approximately equal to the amount of money spent in Canada on construction of the telescope and its components, on engineering or other services, or in direct payments (e.g. salaries and expenses) to Canadian experts working on the site in Chile; a Canadian development team will have to participate throughout the project, commencing immediately. (Note: Canada's contribution should include a 50 per cent interest in the real property of the observatory in Chile; consequently it is to be expected that about 85 per cent of the contribution would be in fact spent in Canada with the remainder funding Canadian interests and activities in Chile.)

5. That the grinding shop for the 200-inch mirror be constructed in Vancouver, on the campus of the University of British Columbia, that it be the property of Canada and not of the CARSO project, and that the shop's primary obligation to the CARSO project be clearly recognized.

6. As a result of (5) above, that, subject to non-interference with the grinding of the mirrors required for the CARSO project on the accepted schedule, Canada will be free to use these facilities to grind the 150-inch mirror for the WESTAR group and any other mirror for any other astronomical observatory elsewhere, without reimbursement to the Carnegie Institution.

7. That an acceptable agreement for the construction and operation of the observatory be drawn up with the Government of Chile.

8. That the agreement with the Carnegie Institution contain a mutually-acceptable withdrawal clause in case the international situation deteriorates to an unacceptable level.

9. That the agreement contain a clause to cover future cooperation between the Mount Palomar Observatory and the non-optical observatories in Canada.

10. That the Canadian parties involved in this agreement come to a clear understanding that Canadian industry will participate to the maximum possible extent with respect to the expenditure of the monies to be spent in Canada and in addition that the Federal Government will undertake only those activities in connection with the manufacture and construction of the observatory and its components allocated to Canada in which there exists neither industrial nor university competence, nor the prospect of developing it within a reasonable time.

Details with respect to these conditions are given in the subsequent paragraphs of this report.

The Science Council has also considered the need for greater coordination of activities in astronomy, both optical and radio, within Canada and recommends —

(a) That an Astronomy Board be established, to advise the President of the National Research Council on all aspects of policy and funding for astronomy in Canada.

(b) That the membership of this Board be drawn from all sectors (government, university and industry) of the scientific community with interests in the major fields of astronomy; to ensure wide representation and a healthy turnover, on-going consultation with all three sectors on membership of this Board should be a continuing practice.

(c) That the Chairman of this Board be elected from its membership, to serve for a specific term of office.

(d) That government activities in astronomy be centralized in the National Research Council.

(e) The management of the grinding shop, mentioned in condition (5) above, should be such as to enhance its capability to become a competitive industry, consistent with its obligations to the CARSO project.

INDUSTRIAL ADVANTAGES

There are nine ground-based major optical telescopes (150-inch and above) planned for construction in various parts of the world over the next ten years along with probably twice this number of more modest size, in the 40- to 80-inch range. Such a total program will involve expenditures of more than $100 million in the decade.

In addition there will be a number of very precise mirrors required for space telescopes including a 120-inch diffraction-limited mirror for NASA. With modern grinding facilities located on the campus of the University of British Columbia in connection with the CARSO program, Canada would be in a good position to acquire the contracts for grinding mirrors for other countries. For example, engineering design contracts have already been obtained by Dilworth, Secord and Meagher and Associates Ltd., Toronto and Vancouver, for the Anglo-Australian 150-inch telescope and the mirror support system for the Kitt Peak National Observatory's two 150-inch telescopes. We think this firm will be able to conclude other contracts on the basis of Canada's clear identification with major telescope construction. Moreover we expect Canadian companies will be able to bring substantial business to Canada in telescope construction on the basis of the experience gained in participating in the 200-inch telescope project.

The potential for industrial foreign orders for Canadian companies is in part justification for embarking on this project. There will also be the possibility of a metrology centre to serve industry being developed in conjunction with the grinding shop.

ASTRONOMY IN CANADA

Canada has had a place of prominence in the world community of optical astronomy since 1918 when the 72-inch reflecting telescope was commissioned at Victoria, British Columbia. For a short time we were in possession of the world's largest telescope. Our large optical instrument capability was doubled with the commissioning in 1935 of the 74-inch telescope at the David Dunlap Observatory at Richmond Hill, Ontario. In the first half of this century, many notable advances in optical astronomy can be attributed to the Canadian effort, although within the last decade or two, telescopes situated in California with reflectors of 100-inch and more diameter (Palomar, Lick, Mt. Wilson) have been responsible for most of the important new discoveries in

optical astronomy. To proceed further in areas of current research, Canadian optical astronomers clearly need a major instrument.

It is important to recognize that the two major facilities at Victoria and Richmond Hill are already fully utilized and that they are located at sites where viewing conditions are rapidly deteriorating with the approach of urban sprawl.

Radio astronomy is a field in which Canadian astronomers have received world wide recognition. As a result of the invention and deployment of radar in World War II, radio astronomy has enjoyed significant growth in the succeeding decades. Government interest began in 1946 in the Radio Engineering Division of the National Research Council. At that time a small solar instrument was set up outside Ottawa. Development continued and in 1951 a compound interferometer was constructed at Lake Traverse, Ontario. By 1959, an 84-foot steerable paraboloid was constructed in Penticton, British Columbia. This site, which also includes a low-frequency dipole array, is operated by EMR and is called the Dominion Radio Astrophysical Observatory (DRAO). About the same time, NRC started construction of the 150-foot steerable paraboloid at Lake Traverse. Completed in 1966, the 150-foot dish has in its short history made many significant contributions to research. It is felt that this telescope is the best in the world for some wave lengths. The Lake Traverse site has other radio astronomy installations including a 33-foot steerable paraboloid and a 60-foot paraboloid owned by the University of Toronto. Canadian radio astronomers were the first in the world to use two large paraboloids on a long base-line as an interferometer. Employing the 150-foot paraboloid at Lake Traverse and the 84-foot paraboloid at Penticton, they effectively had an interferometer with a base-line of over 2,500 miles. This is a major achievement for Canadian astronomers.

Some Canadian universities are active in radio astronomy, particularly Queen's, Toronto, U.B.C., and Western Ontario. Queen's and Western both own 60-foot paraboloids.

Although radio astronomy does not need a major installation at the present, there is a need for the development of additional and improved receivers for the 150-foot paraboloid. It appears that in about five years, radio astronomy will need another major instrument, perhaps located at DRAO, Penticton.

Astronomy does not only examine the visible and radio frequency portions of the electromagnetic spectrum but the entire spectrum. Although a very large proportion of effort in Canada is in optical and in radio astronomy there is considerable work being done in other fields. Major efforts are in 1) theoretical astronomy, 2) cosmic-ray astronomy, and 3) X-ray astronomy. There is also a small involvement in gamma ray, infra-red and ultra-violet. Theoretical astronomy uses no observational instrument but relies on computers. Cosmic-ray astronomy uses balloons, rockets and satellites to collect needed data. X-ray astronomy is also dependent upon rocket-borne radiation detection equipment. X-ray and cosmic ray astronomy will largely make use of vehicles developed primarily for Canadian and U.S. space programs (i.e., for other purposes).

SCIENTIFIC JUSTIFICATION

Astronomy is judged to hold the potential for many very exciting advances over the next decade, and has substantial public interest as witnessed by the large number of people attending the new planetaria. (It is interesting to note that four new planetaria were constructed as centennial projects.) The annual attendance at all planetaria in Canada is 1,453,000. Astronomy is also an area of increasing enrolment in the universities, again testifying to the interest in astronomy by the coming generation.

It is our view that most of the exciting advances in our knowledge of the universe around us will come through cooperative observations on major optical telescopes and major radio

telescopes, or between one of these and observations in ultra-violet, infra-red or X-ray astronomy. We, therefore, wish to give high priority to the installation of the large optical telescope for Canadian astronomers in the best possible location. This need can be met most economically by joining the Carnegie Institution in the proposed 200-inch telescope in Chile. We have examined the reports on the optical properties of the site in Chile and find them to be outstanding. This installation would not interfere with the intention of the consortium of Western universities to mount a large optical telescope on Mount Kobau. In fact, the establishment of the grinding shop at U.B.C. would be an advantage to the Western group because it could also be used for the grinding of their mirrors.

While the cost of a large optical telescope is substantial, its life expectancy is greater than any other major physical science research installation and when the cost is amortized over the life expectancy of 30 to 50 years it is really quite modest. Council's consideration of the high energy particle accelerator is reported separately but the Council considers that the CARSO Project has higher priority.

It is our assessment that if the CARSO project is approved this would represent the only major expenditure by the Federal Government in the field of optical astronomy for the next 20 years.

ORGANIZATION OF ASTRONOMY

The field of astronomy is in need of positive means of coordination. The debate on the relative merits of the Mount Kobau Project and the CARSO Project has developed tensions among the academic astronomers, and while the division of interest between Energy, Mines and Resources and the National Research Council has produced no serious internal problems it is an unnecessary duplication. Particularly in the field of radio astronomy the support in electronic and electrical engineering available from the National Research Council is a substantial advantage and, therefore, there are clear-cut arguments for combining all government radio astronomy in the National Research Council. It is essential that optical and the other forms of astronomy be under the same general direction as radio astronomy because of the anticipated major advances being made with close coordination between these various segments of astronomy, and consequently we conclude that NRC should become the focus for federal interest in astronomy.

There are strong astronomical interests in the universities as well as in government and there will be increasing interest in industry because of the potential foreign business. We feel that coordination of these interests is essential for maximum productivity and the most effective use of resources. The Astronomy Board will bring all segments of the discipline together for best planning and coordination.

SUPPLEMENTARY ADVANTAGES

The operation of the CARSO Observatory would bring Canadian universities into contact with the Chilean universities and would, therefore, enhance the nossibilities of meaningful technical assistance to these universities from their Canadian counterparts.

CANADIAN ASTRONOMERS

Canadian scientific expertise in astronomy has international recognition* and we are confident that Canada's astronomers would make imaginative and productive use of their time at the CARSO

*e.g. Dr. Donald McCrae (Professor and Chairman of Astronomy, University of Toronto and Director, David Dunlap Observatory) has been named head of the newly formed "Universities space Research Association" of the United States, an organization which has been established to work directly with the Manned Space Centre at Houston.

Observatory. Their technical skills in grinding and instrumentation are substantial and this is a particular strength of DAO in Victoria. These skills would be enhanced and spread to the industrial sector by means of this project. Other appropriate skills in industry would be developed. Participation in the project would enable Canadian astronomers to stay in the forefront of their field and would provide enrichment to their undergraduate teaching.

OPERATING EXPENSES

The operating expenses of the Observatory in Chile would build up slowly over the ten-year construction period as various facilities are commissioned. When fully operational, it is estimated that the annual operating costs would be about $830,000 of which Canada would pay 50 per cent. Having studied the expected growth of astronomy in Canada (based on the known growth of undergraduate enrolment and the consequent need for teachers), we have concluded that the provision of those monies through the normal channels will constitute no aberration and therefore, as far as we can see at this time, will require no special provisions.

If the WESTAR group succeeds in completing an observatory on Mount Kobau, we presume that the astronomers concerned would be eligible to apply for support through the normal channels and that their requests would be judged in competition with other submissions for the support of fundamental research from available funds.

CONCLUSIONS

We have examined other agreements that could be entered into with other national consortia constructing large telescopes but the agreement with the Carnegie Institution appears to be the most favourable because, first, it would bring substantial industrial work to Canada; second, funds provided by the Canadian government would almost all be spent in Canada; third, it would provide a guarantee of observing time on what will be the most advanced facility in the world; and fourth, the scientific merits of the project are undoubted.

The Council has been invited to consider the priority of the CARSO project in the light of "the theoretical assumption that the proportion of the budget available for fundamental research in the immediate future would be the same proportion of the gross national product as it is today". The Council would foresee no problem in accommodating the funding of the CARSO project under such circumstances, but would naturally hope that expenditures on research and development in general would grow at a more rapid rate than that implied in the hypothesis. Indeed, we are sufficiently convinced of the merits of this project that we would recommend that, if necessary, other activities now funded should be curtailed to provide the money for the CARSO observatory. If the needed funds have to come from the portion of the federal budget allocated to fundamental research, we would still so recommend.